

Predicting the Potential for Historical Coho, Chinook and Steelhead Habitat in Northern California

Draft Version

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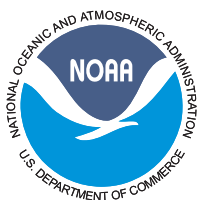
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1 Introduction

Numerous Evolutionarily Significant Units (ESUs) of salmon and steelhead in California and the Pacific Northwest have been listed under the U.S. Endangered Species Act (ESA). In response, NOAA Fisheries has convened Technical Recovery Teams (TRTs) to develop biological viability criteria for the listed ESUs. An understanding of biological structure is a critical first step to assessing population viability and potential persistence of ESUs (Meffe and Vrijenhoek, 1988; McElhany et al., 2000). TRTs therefore evaluate population structure within each ESU under historical conditions, as this structure is the result of ecological and evolutionary dynamics that played out across the physical and ecological landscape before recent anthropogenic disruption. The historical structure of an ESU therefore represents a state for which we are most certain that the ESU was likely to persist over long time scales, and serves as a “baseline” for evaluating the status of an ESU under current or projected conditions. Since populations that were important to ESU persistence in the past are likely to be important to ESU persistence in the future, understanding the historical template is critical to reducing uncertainty in assessments of current or future scenarios.

Unfortunately, historical data are sparse and of limited spatial extent or resolution, and information on current conditions is often insufficient or are too influenced by anthropogenic disruption of natural processes to support inference regarding historical structure within a given ESU. TRTs for coastal California and Oregon¹ have therefore decided to adopt a GIS-based modeling approach to predict historical population structure as a function of the geomorphic and hydrologic processes that generate suitable freshwater habitat for critical life-history stages of each species. This approach to broad-scale classification of areas according to their “intrinsic potential” (IP) to exhibit suitable habitat was originally developed for coho salmon and steelhead watersheds draining the Coast Range of Oregon (Burnett et al., 2003), and is being used to support analysis of historical population structure for the Oregon Coast Coho Salmon ESU and the three ESUs in the

¹Two TRTs are charged with developing biological viability criteria for five listed ESUs of salmon and steelhead that occupy watersheds tributary to the Pacific Ocean between the Columbia River (exclusive), and northern Monterey Bay, California. The TRT for the Oregon/Northern California Coast (ONCC) Recovery Domain is charged with analyses for the Oregon Coast coho salmon (OC-coho) and Southern Oregon/Northern California Coast coho salmon (SONCC-Coho) ESUs. The TRT for the North-Central California Coast (NCCC) Recovery Domain is charged with analyses for the Central California Coast coho salmon (CCC-Coho), North-Central California Coast steelhead (NCCC-Steelhead), Central California Coast steelhead (CCC-Steelhead) ESU, and California Coastal Chinook salmon (CC-Chinook) ESUs.

NCCC Recovery Domain (Lawson et al., 2004; Bjorkstedt et al., 2005).

In this report, we describe our implementation of this approach to coastal watersheds between Cape Blanco, Oregon, and Monterey Bay, California, and provide a technical description for GIS data sets developed for listed ESUs of salmon and steelhead in this region. Specifically, we adapt the approach developed by Burnett et al. (2003) to predict IP for spawning and rearing habitat of coho salmon (*Oncorhynchus kisutch*), winter steelhead (*O. mykiss*) and fall-run Chinook salmon (*O. tshawytscha*). Note that we do not assess intrinsic potential for summer steelhead and spring-run Chinook salmon because these life-history strategies have very specific habitat requirements (e.g., deep, cold pools in which the adults spend the summer) that are not readily predicted from available GIS data. In addition to the technical description of the model and analysis, we also offer guidance regarding appropriate interpretation and use of these results in recovery planning for listed salmonids.

2 Intrinsic potential: concept and general model

The concept of a stream’s “intrinsic potential” to exhibit suitable habitat for a particular species or life stage emanates from a hierarchical perspective of fish-habitat relationships (sensu Frissell et al., 1986; Montgomery and Buffington, 1998). In this view, landform, lithology, and hydrology interact to govern movement and deposition of sediment, large wood, and other structural elements along a river network. These larger-scale characteristics and processes thereby control gross channel morphology at the scale of stream segments or reaches, as reflected in the frequency and characteristics of constituent habitat units (e.g., pools, runs, riffles, side-channels, etc.). The IP concept assumes that this hierarchy of organization, structure, and dynamics of physical habitat is reflected in the biological organization of stream communities. In the case of salmonids, the biological response manifests itself as heterogeneity in the distribution, abundance, and productivity of different species and life stages within a river basin’s stream network. The underlying framework for the IP models used in this analysis assumes that three primary indicators of landform and hydrology - channel gradient, some index of valley width, and mean annual discharge - serve as reasonable predictors of channel morphology and hence the potential for a particular reach to express habitat conditions favorable to a particular salmonid species at some stage of its life. These characteristics are effectively constant features of the landscape, and thus provide the basis for predicting both potential habitat under historical conditions, and the potential for physical processes to recreate suitable habitat if left to operate more or less naturally. Among-species or life-stage differences

in habitat affinities are accommodated through species-specific curves relating suitability to the three physical metrics.

Burnett et al. (2003) describe a practical model in which stream reach characteristics are translated into a measure of intrinsic potential in two steps. First, reach-specific values for each characteristic (i.e., gradient, valley constraint, and mean annual discharge) are converted to habitat suitability scores through functions (“suitability curves”) that map the value of each variable to a scale of 0-1. Suitability curves are specific to species and life-history stage (see §3.3 below). Suitability scores express the “likelihood” that suitable habitat will occur in a reach with a particular value for a characteristic, independent of the value of the other characteristics. In general the form of the relationship between reach characteristics and habitat suitability is not known precisely. What often is reasonably well known is the range of values for a given characteristic that almost always yield favorable habitat as well as the range of values for which favorable habitat almost never occurs. Given the uncertainty associated with intermediate values, a simple linear relation is generally assumed to fill in the gap between values corresponding to “good” and “poor” habitat potential. Note that regardless of life-history stage, the upper extent of tiny positive values for gradient reflects the ability of adults to ascend reaches of varying steepness, and thus defines the range of accessible habitat.

Second, reach-specific IP is calculated as the geometric mean of reach-specific suitability scores for each of the three characteristics². Combining the marginal effects of each reach characteristic in this way is directly analogous to the theoretical basis of a limiting factors analysis: a low value based on a single characteristics will dramatically reduce or zero-out IP for a stream reach, and in these instances, other reach characteristics are uninformative with respect to habitat potential.

3 Implementation south of Cape Blanco

In the following sections, we provide a brief overview of the basic approach outlined in (Burnett et al., 2003), but focus in more detail on specific nuances of our implementation of the IP model for watersheds south of Cape Blanco.

²Mathematically, for stream reach k , $IP_k = \sqrt[3]{f_D(D_k) \cdot f_G(G_k) \cdot f_V(V_k)}$, where D_k , G_k , and V_k are mean annual discharge, gradient, and valley constraint, respectively, of reach k , and each f_x maps the appropriate characteristic x onto a scale of 0-1.

3.1 Generating stream networks and reach attributes

Calculating IP is a multi-step process that occurs both outside and inside a GIS. The first step is to create a stream network from the DEM and precipitation data that defines individual reaches and calculates values of gradient, valley floor width and discharge for each. The second step is to create the suitability curves for these three variables based on life-history and habitat association of each species and life-stage. Finally, to marry these two steps, Burnett et al. (2003) wrote a series of species-specific processing scripts (Arc Macro Language, Environmental Systems Research Institute, Inc.³) to calculate the IP score for each reach.

To construct a stream network, we implemented models developed by Miller (2003) to synthesize information on topography derived from a 10m resolution Digital Elevation Model (DEM)⁴ and mean annual precipitation derived from the PRISM model (Daly et al., 1994)⁵. The model requires two geographic datasets (elevation and precipitation) and a file of model parameters. To run the model (which is implemented outside of a GIS in a series of Fortran programs) we generated binary files of the elevation and precipitation grids. Beginning with the larger regional-scale elevation and precipitation grids we used polygon boundaries to clip out the DEM and precipitation files at the watershed extent. The last input needed is a parameters file, and the only substantial changes made to the default inputs were to include regionally-specific equations relating precipitation to discharge (See §3.2 for specifics). This analysis is conducted on a watershed by watershed basis. Watersheds were defined *a priori* based on 1:100K hydrography (USGS 2003), sixth-field hydrologic unit code (HUC) boundaries (FRAP 1999; NRCS 2002), and where required, manual delineation informed by topography. For very large basins (e.g., the

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⁴10 m DEM coverage was not available for the entirety of our study region at the time of analysis. Therefore, where seamless, original 10 m DEM coverage was not available, we generated a 10 m DEM by applying a spline to interpolate a seamless 30 m resolution DEM to 10 m resolution. Comparisons of derived properties (e.g., stream gradient) aggregated at watershed scales, and the general structure of resulting watersheds show negligible differences between analyses based on interpolated 10 m DEMs and analyses based on independently derived 10 m DEMs.

⁵The PRISM data set is a mean climatology derived by interpolating climatic observations from the period 1961-1990 at a spatial resolution of 2km by 2km. The interpolation scheme accounts for the influence of elevation, aspect, and proximity to the coast on climatic variables such as temperature and precipitation (Daly et al., 1994).

Rogue, Klamath, and Eel rivers), it was necessary to analyze major tributaries and sections of mainstem river separately, and subsequently to reassemble the basin in GIS⁶. For each watershed, the model creates several output layers, including: Flow Direction of the raster streams within the watershed (Tarboton Method), Flow Accumulation of the streams, and a vector version of the DEM derived streams (whereby each reach includes information on the three variables that serve as the basis for IP: gradient, valley constraint, and mean annual discharge).

In the course of constructing the stream network, Miller’s 2003 model dynamically defines reaches on the order of 50-200 meters in length, using changes in gradient as the basis for identifying appropriate break points. In the resulting stream network, each reach is characterized by its gradient (averaged over the entire reach), valley width⁷, and mean annual discharge (calculated at the downstream end of the reach).

Post processing on each of the three variables generated by Miller’s 2003 model also occurs within the GIS; specifically, gradient is calibrated based on field measurements, discharge is converted to metric units, and valley floor width is used to generate the index of valley constraint (Burnett et al., 2003)⁸. Note that the stream network and its attributes are the basis for all subsequent calculations, regardless of species or life-history stage.

3.2 Accounting for latitudinal gradients in climate

By implementing the IP model directly, we implicitly assume that geomorphic structure and precipitation interact to generate stream networks in northern California in a manner similar to that observed in watersheds of coastal Oregon for which the IP model was

⁶Miller’s 2003 model includes a Fortran routine to “stitch” the sub-watersheds back together. This routine ensures matching stream topology during reassembly, and transfers discharge values from the stream at the outlet of the upstream watershed to the “headwater” stream of the downstream watershed.

⁷Miller (2003) explains that valley floor width is “estimated as the length of a transect that intersects the valley walls at a specified height above the channel. Since the orientation of the valley is unknown, transect orientations is varied to find that which provides the minimum length. The height above the channel is specified as 2.5 times estimated bank-full depth, given as a function of drainage area. The value is currently coded in as $H_{bf} = 0.36A^{0.2}$, where H_{bf} is bank-full depth and A is drainage area in square kilometers (based on data in Benda (1994)). Thus the height above the channel from which the transect is extended varies from a little less than a meter for small streams to a little over three meters for large streams.”

⁸Burnett et al. (2003) derived an index of valley constraint by dividing valley floor width by active channel width, the latter of which was calculated as follows, $V_k = 2.19108 + 1.32366 * \sqrt{D}$, where V_k represents valley constraint, and D is mean annual discharge (in ft^3/s).

originally developed. We attempted to evaluate this assumption, and if necessary, to correct the underlying model, by estimating regional models for mean annual discharge as a function of catchment area and mean annual precipitation. To accomplish this, we assembled discharge data for stream gages with at least 20 years of data during the period for which the climatological data set was developed, and for which there was little or no evidence of substantial upstream diversion, extraction or elevated evaporative loss⁹. Preliminary analyses indicated that the relation of mean annual discharge to catchment area and mean annual precipitation in the SONCC Recovery Domain was essentially identical to that observed in coastal Oregon, and the final model used for coastal watersheds throughout the study area was also very similar to that used for coastal watersheds north of Cape Blanco¹⁰. On the basis of substantial climatic differences, we estimated a separate model to predict discharge in watersheds in the San Francisco Bay¹¹.

3.3 Suitability curves

Suitability curves are defined for each reach characteristic, and are specific to a species and life-history stage. These functions are used to map reach-specific values for each of the three attributes to a scale of 0-1, and the resulting scores represent the effects of each physical attribute on the potential of a stream reach to exhibit high quality habitat. Our ability to measure “habitat quality” directly is extremely limited, and available data sets, while informative, are generally insufficient to support extensive, rigorous statistical estimation of the functional relationship between all three stream characteristics and their marginal effects on habitat quality. Suitability curves, therefore, represent expert synthesis of data on fish distributions in the context of general habitat requirements of a

⁹Gages were excluded on the basis of evidence of direct diversion extracted from Agajanian et al. (2002), Christy (2003), or (USGS). Estimates of extractions for irrigation were compiled from estimates of irrigated area and HUC-level irrigation rates using information in Solley et al. (1998) and Vogelmann et al. (2000). Actual or estimated evaporation rates were used to evaluate losses from non-diversion reservoirs. If estimated evaporation rates or diversions for irrigation or water supply from the watershed above a particular gage exceeded 2% of mean annual discharge, that gage was excluded from further analyses.

¹⁰The final model for the region spanning coastal watersheds from Cape Blanco to Santa Cruz predicted mean annual discharge, D (in m^3s^{-1}) according to $\ln(D) = -11.445 + 1.003 \ln(A) + 1.467 \ln(P)$ ($n = 29$, $r^2 = 0.988$), where A is (planar) catchment area in ha and P is mean annual precipitation in mm. For comparison, the relation for coastal Oregon is $\ln(D) = -11.972 + 0.99 \ln(A) + 1.593 \ln(P)$. Note that these models are of the same form as those developed by the Oregon Department of Forestry (Lorensen et al., 1994) and used by Miller (2003) and Burnett et al. (2003).

¹¹Based on data for San Francisco Bay and watersheds in the western Central Valley, we estimated $\ln(D) = -13.047 + 0.876 \ln(A) + 2.171 \ln(P)$ ($n = 20$, $r^2 = 0.968$).

particular life-history stage of a particular species. Typically, such syntheses are based on density estimates (e.g., the number of juvenile coho salmon per 100 m of stream), which are assumed to provide a suitable measure of the amount of high quality habitat in a reach, across a range of habitat characteristics. This approach—although not extensively published in the formal peer-reviewed primary literature—has been through extensive peer and public review during the course of the Umpqua Land Exchange Project (ULEP) and Coastal Landscape Analysis and Modeling Study (CLAMS) efforts in Oregon.

Figure 1 illustrates the suitability curves used to calculate IP for the relevant life history stages of each of the three species addressed in this report. These curves are based on those from CLAMS which were themselves preceded by the “index values” of ULEP. Table 1 provides some of the historical references used in the development of these curves, and additional data sets that we consulted in the course of evaluating whether relationships between stream characteristics and fish distributions provided evidence that different suitability curves were required for coastal watersheds. With the exception of Engle (2002), none of these data suggested that altering the curves for application to California was warranted. Based on Engle’s 2002 work, we extended the range of gradients that were accessible to adult steelhead and consistent with high likelihood of suitable habitat for juvenile steelhead (Figure 1). We also reduced slightly the suitability of highly constrained reaches for juvenile steelhead in order to recognize that these fish also make use of (and perform well in) habitats such as pools that are less common in highly constrained reaches.

3.3.1 Life history context for suitability curves

Understanding the ecology and habitat requirements of a given species at its various life history stages is useful for interpreting and understanding the distribution of IP scores within a basin. We therefore provide below a brief description for the relevant life history stage for each of the species addressed in this report.

Juvenile coho salmon Juvenile coho salmon exhibit traits, such as relatively large fins and laterally compressed bodies, that are believed to be adaptations to living in the slower-velocity habitats where they most commonly occur. During the summer, juvenile coho salmon generally exhibit preference for pool habitats over runs and riffles (Bisson et al., 1988). During the winter, juvenile coho salmon often move out of the main channel and seek refuge in side channels, alcoves, and other off-channel habitats during periods of high stream discharge (Tschaplinski and Hartman, 1983; Meehan and

Bjornn, 1991; Bell et al., 2001). Together, these attributes and behaviors likely explain why juveniles are most abundant in low-gradient (usually <2%-3% but occasionally up to 5%), unconstrained reaches as opposed to constrained reaches or steeper headwater streams. Spawning tends to occur in areas with characteristics similar to those where juvenile rearing habitats are likely to occur. The juvenile phase spans at least one summer and one winter in freshwater, although some individuals may spend an additional year in freshwater.

The suitability curves that form the basis of IP predictions for juvenile coho salmon reflect the likelihood that stream reaches will exhibit substantial pool and off-channel habitat as a function of their geomorphological and hydrological characteristics (Figure 1a-c). These suitability curves are identical to those used by Lawson et al. (2004) to predict IP for watersheds in coastal Oregon.

Juvenile (winter) steelhead The spawning distribution of steelhead overlaps with that of coho salmon; however, because steelhead tend to prefer higher gradients (generally 2-7%, though they may be found in reaches with gradients up to 12% or more), their distribution tends to extend farther upstream. In some watersheds, steelhead will even spawn in ephemeral streams, with juveniles migrating downstream to permanent waters to rear. Following emergence in spring, fry typically adopt feeding stations in shallower portions of riffles or pools, moving into progressively faster and deeper water as they increase in size (Bisson et al., 1988). Juvenile steelhead exhibit a streamlined body morphology that is thought to be an adaptation for life in faster water currents (Bisson et al., 1988). Although steelhead tend to prefer and grow faster in pool habitats, as young-of-the-year, they are commonly displaced to riffle habitats through competitive interactions with larger, more aggressive coho salmon when the latter are abundant (Bugert and Bjornn, 1991; Young, 2004). Such displacement is not observed for older, larger juvenile steelhead. The juvenile phase spans at least one summer and one winter in freshwater, but is more variable and of greater maximum duration than is observed for coho salmon.

The suitability curves that form the basis of IP predictions for juvenile steelhead reflect the likelihood that stream reaches will exhibit substantial higher-energy habitats such as runs and riffles as a function of their geomorphological and hydrological characteristics (Figure 1d-f). To some degree, these curves implicitly include the consequences of ecological interactions with coho salmon; however, these interactions take place at local scales, and in most if not all cases where juvenile coho salmon occur, they are sympatric with juvenile steelhead at the reach scale. Note that although we found no support for

implementing a temperature-based constraint on the predicted distribution of steelhead in our study area¹², juvenile steelhead are not likely to experience substantial “competitive release” with respect to the distribution of high quality habitat in areas where coho salmon are excluded by temperature. Instead, since the metabolic demands of juvenile steelhead increase with temperature, it is likely that juvenile steelhead will continue to favor higher velocity habitats that provide a greater rate of drift to supply their increased foraging needs (Smith and Li, 1983).

Fall-run Chinook salmon Fall-run Chinook salmon occur in rain-dominated systems or the lower portions of systems with both rain and snowmelt influence, and tend to spawn in low-gradient reaches with greater discharge that are somewhat lower in a watershed than reaches used by steelhead. Ocean-type juveniles, which are typical of fall-run populations, may begin migrating toward sea within a few weeks to a few months of emergence, but some individuals may reside in streams in rivers through the summer months, before moving to estuaries during the fall or winter (Reimers, 1973; Healy, 1991; Moyle, 2002).

The suitability curves that form the basis of IP predictions for fall-run Chinook salmon reflect the dominance of gradient and discharge in determining where suitable habitats are likely to occur (Figure 1g-i). Fall-run chinook tend to be less dependent as juveniles on off-channel habitats that provide refuge from high flows, which reduces the control of valley constraint on intrinsic potential.

¹²Analysis of environmental predictors of presence for steelhead in the South-Central California Coast ESU (D. Boughton, NOAA Fisheries, Santa Cruz Lab, *unpublished results*) suggests that mean August air temperature exceeding 24 °C might limit the distribution of steelhead, a value corroborated by similar analysis of the effects of water temperature on presence of *O. mykiss* (Eaton et al., 1995). Very little of our study area experiences these conditions.

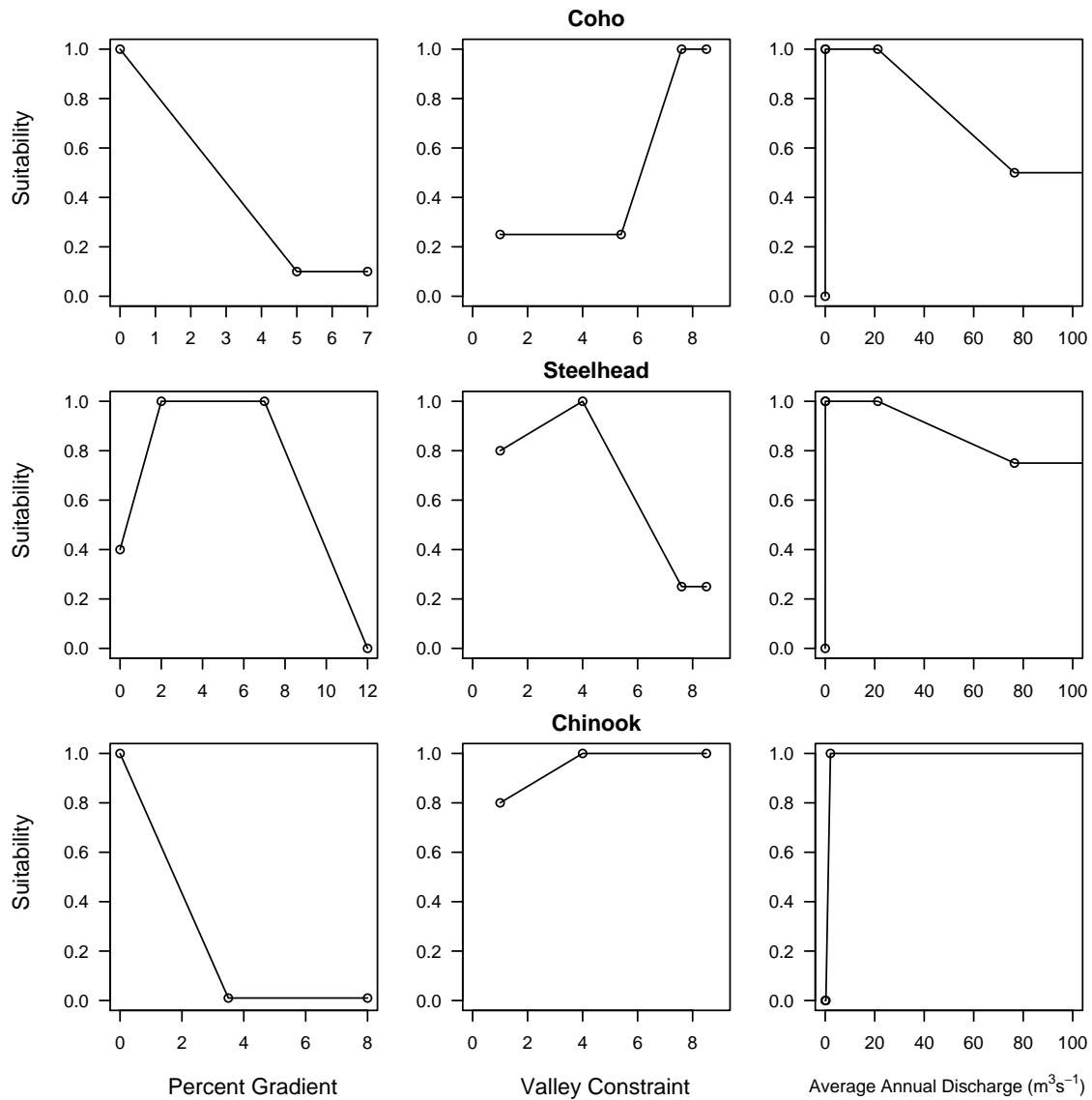


Figure 1: Suitability curves for each of the three IP components (Gradient, Valley Constraint and Discharge) for each of the three species (coho, steelhead and chinook). Note the scale change (abscissa) across each species for the gradient attribute.

Table 1: Sources of information synthesized through expert opinion to develop suitability curves for ULEP, CLAMS, or this report.

Attribute	coho salmon	steelhead	Chinook salmon
Gradient	<p>Hicks (1989)</p> <p>Reeves et al. (1989)</p> <p>Schwartz (1991)</p> <p>Nickelson and Lawson (1996)</p> <p>Nickelson (1998)</p> <p>Hicks (1989)</p> <p>Schwartz (1991)</p> <p>Scarnecchia and Roper (2000)</p> <p>Burnett (2001)</p> <p>Hicks and Hall (2003)</p>	<p>Hicks (1989)</p> <p>Dambacher (1991)</p> <p>Schwartz (1991)</p> <p>Roper et al. (1994)</p> <p>Scarnecchia and Roper (2000)</p> <p>Burnett (2001)</p> <p>Harvey et al. (2002)</p> <p>Engle (2002)</p> <p>Hicks and Hall (2003)</p> <p>Armantrout (2005)</p>	<p>Schwartz (1991)</p> <p>Roper et al. (1994)</p> <p>Scarnecchia and Roper (2000)</p> <p>Burnett (2001)</p> <p>Armantrout (2005)</p>
Constraint	<p>Hicks (1989)</p> <p>Schwartz (1991)</p> <p>Nickelson and Lawson (1996)</p> <p>Burnett (2001)</p> <p>Hicks and Hall (2003)</p>	<p>D’Angelo et al. (1995)</p> <p>Burnett (2001)</p> <p>Harvey et al. (2002)</p> <p>Hicks and Hall (2003)</p>	
Discharge	<p>Sandercock (1991)</p> <p>Rosenfeld et al. (2000)</p> <p>Burnett (2001)</p>	<p>Meehan and Bjornn (1991)</p> <p>Behnke (1992)</p> <p>Burnett (2001)</p>	

3.4 Example: Ten Mile River

Plates 1, 2, and 3 illustrate examples of results from implementation of the model to the Ten Mile River in Mendocino County, California.

3.5 Temperature limitation for coho salmon.

Preliminary examination of the output from the IP model indicated regional discrepancies between historical records and the extent of areas with high IP for juvenile coho salmon. These discrepancies were most apparent in inland areas where an additional factor, summer water temperature, might approach or exceed the tolerable limits for juvenile coho salmon (Eaton et al., 1995), and thus might preclude use of areas that otherwise appear suitable. TO account for these discrepancies, we combined information on the historical distribution of coho salmon (Spence et al., 2005) and mean August air temperature extracted from the PRISM climatology to develop temperature-based “masks.” We then used these masks to exclude habitat by zeroing out the IP score for stream reaches in areas that were excessively warm for coho salmon. Specifically, we selected 335 streams for which Spence et al. (2005) found either (1) direct evidence of coho salmon in the form of documented first-hand observations of coho salmon, or (2) direct assertions by professional fishery biologists familiar with the particular region that indicated a strong likelihood of coho salmon presence. For each of these streams, we extracted and plotted the lowest mean August air temperature (LMAT) in the contributing watershed. A pronounced decrease in the number of streams with coho present was indicated as LMAT approached 21 - 22°C. Ninety five% of watersheds known to have historically supported coho salmon had LMAT values $\leq 21^\circ\text{C}$ and 99% had LMAT values $\leq 22^\circ\text{C}$ (Figure 2). To support sensitivity analyses by the TRTs, we generated separate IP layers for areas with LMAT exceeding 21°C, 21.5°C, and 22°C (see, for example, Plate 4). Note that this approach is consistent with the intrinsic potential concept; we elected not to incorporate temperature directly into the model of Burnett et al. (2003) (i.e., calculation of the geometric mean) in order to preserve comparability of predictions from the original model along the coast.

3.6 Natural Barriers

The ability of this type of application to locate where natural barriers exist in a watershed, is dependent on the resolution of the DEM. At 30 m resolution, clearly the application will have difficulty locating anything other than massive barriers in the stream. However

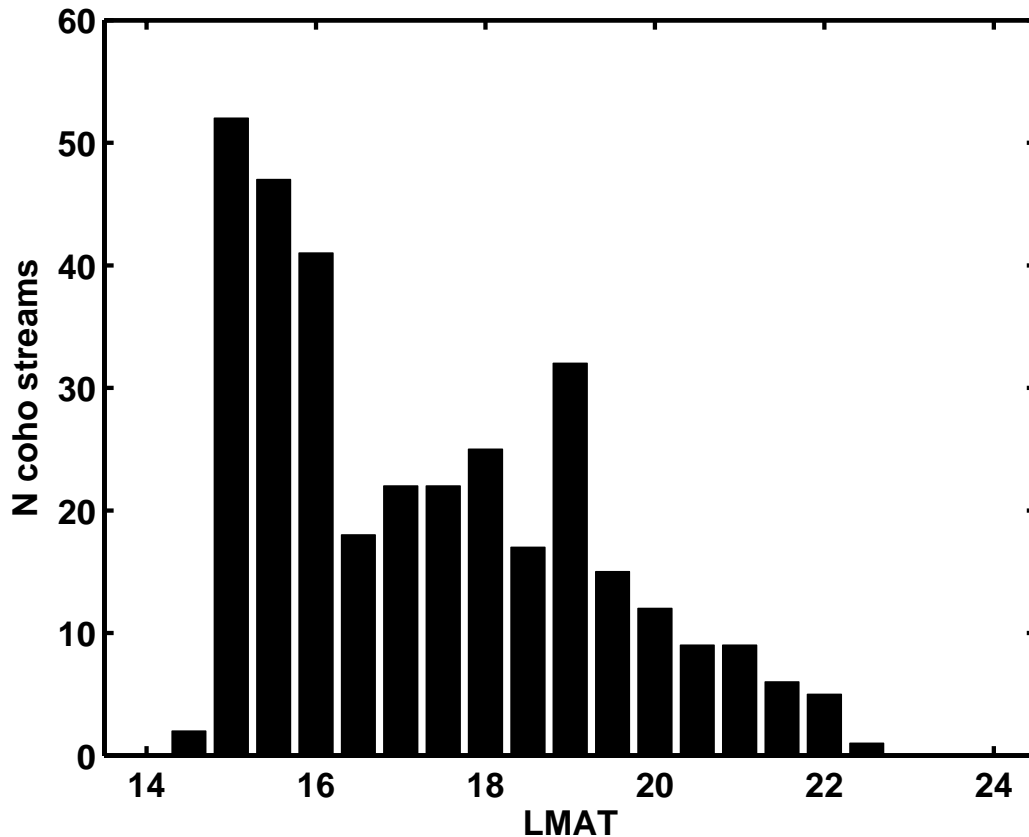


Figure 2: Lowest mean August temperature (LMAT) within catchment areas of historical coho-bearing streams in the Central California Coast Coho Salmon ESU.

at 10 m, it was our experience that the Miller-Burnett application did a good job at picking up known natural barriers. It does, however, fail to resolve barriers smaller than 10 m. For our verification, we took known barriers in the Mad River, and determined how well the application picked up these barriers. While we did not quantify the results, it was our general impression that the code was catching major barriers to anadromy. Users with enhanced local knowledge of a system will be able to use the gradient attributes within the IP layer to test how well the code is working. Where it fails to resolve known barriers, nodes can be digitized into the linework, upstream arcs can be traced, and then flagged as “behind” a barrier.

4 Interpretation and appropriate use of intrinsic potential

The focus of the IP modeling framework is to predict the likelihood—strictly speaking, the relative likelihood—that a stream reach will exhibit suitable habitat for a particular life history stage of a particular species. Keeping this in mind is critical for appropriate interpretation of model predictions, and for understanding the assumptions invoked in going beyond the strict definition of IP. The models predict neither the actual, fine-scale distribution of habitat within a basin nor the quality of habitat in a given reach under current or historical conditions. With respect to this definition, predictions of IP presented here are likely to be relatively robust to differences in hydrology associated with seasonal and latitudinal precipitation variation. In other words, within much of the range of conditions observed in coastal watersheds of southern Oregon and northern California, it is likely that stream reaches exhibiting the right combination of characteristics will exhibit similar probabilities to provide suitable habitat. The most likely exceptions to this pattern arise in basins that exhibit substantially warmer, drier conditions, such as watersheds tributary to the eastern and northern San Francisco Bay.

The relatively robust nature of predictions for the (relative) likelihood that suitable habitat exists almost certainly does not extend to further extrapolations from the concept of IP, such as attempts to translate predictions of IP into some measure of historical carrying capacity of a watershed (e.g. Lawson et al., 2004; Bjorkstedt et al., 2005; Williams and SONC/TRT, 2005). Such exercises invoke assumptions regarding how IP is translated into a measure of habitat capacity and, in turn, into a measure of fish abundance. These assumptions are likely to be more sensitive to differences in climate that affect how seasonal winter precipitation translates into summer stream discharge. This is particularly important if there also exists a latitudinal gradient in the relative importance of winter versus summer habitat as a factor limiting population size or productivity in coho salmon and steelhead. An analogous issue arises for fall-run Chinook salmon for which the timing and intensity of early winter storms can strongly affect the ability of these fish to enter freshwater. Thus, any use of IP that goes beyond the strict conceptual definition of IP requires careful consideration of the assumptions required to do so and potential biases that arise from any violation of these assumptions.

5 Description of the GIS database

5.1 Distribution

The IP streams data are available for distribution as GIS coverages in .e00 form (ESRITM proprietary export and interchange file type). Please contact Dr. Peter Adams, Fisheries Branch Chief, Southwest Fisheries Science Center, Santa Cruz Laboratory, at 831-420-3923, or Pete.Adams@noaa.gov for information on acquiring the data. The data are available for all the anadromous populations in our purview. This ranges from the Rogue River basin in Southern Oregon to the Tijuana River in Southern CA, and includes the steelhead ESU in the Central Valley, however, IP implementation in the Central Valley and Southern California recovery domains is different from that noted here. Consult Lindley et al. (2005) and Boughton and SCACO/TRT (2005) for specifics of those implementations. We have created a master metadata file that describes, in detail, each of the attributes generated at the different processing steps. Where a given watershed exists in multiple ESUs, the IP coverages contains IP information for the different species. Streams in the NCCC also include summaries of the temperature masked IP (See §3.5). Lastly, there are no current plans to update the IP streams; they are distributed as is.

5.2 Usage within a GIS

The IP data exist for all watersheds containing anadromous populations of salmonids in our study area (Southern OR to the CA/Mexico border). For large watersheds with multiple sub-populations, we have delineated the areal extent of the sub-populations and calculated IP at that level. For example in the Klamath River, we have IP streams for the Scott, the Shasta, and the Salmon, etc., but not for the entire Klamath basin. (Since the files are at 1:24k, the Microsoft Windows file size limit constrains total size.) Several of the smaller coastal basins were lumped and calculated as one watershed. The streams data are at approximately a 1:24k scale; however, the data do not contain stream names or other identifying attributes (e.g. LLID), nor does a route system exist for the streams. To locate IP on particular reaches on specific named streams, one would have to navigate using a named stream system, e.g. CA 1:100k routed hydrography (Christy, 2003) (see Data Downloads section of <http://www.calfish.org>; available for download at ftp://ftp.streamnet.org/pub/calfish/cdfg_100k_2003_6.zip). With the following attributes: co_ip_curve (coho), chk_ip_curve (chinook), and st_ip_curve12 (steelhead) and a graduated color ramp within the GIS, users can recreate the figures shown herein. Consult the metadata for specifics on the additional attributes within the data

layer.

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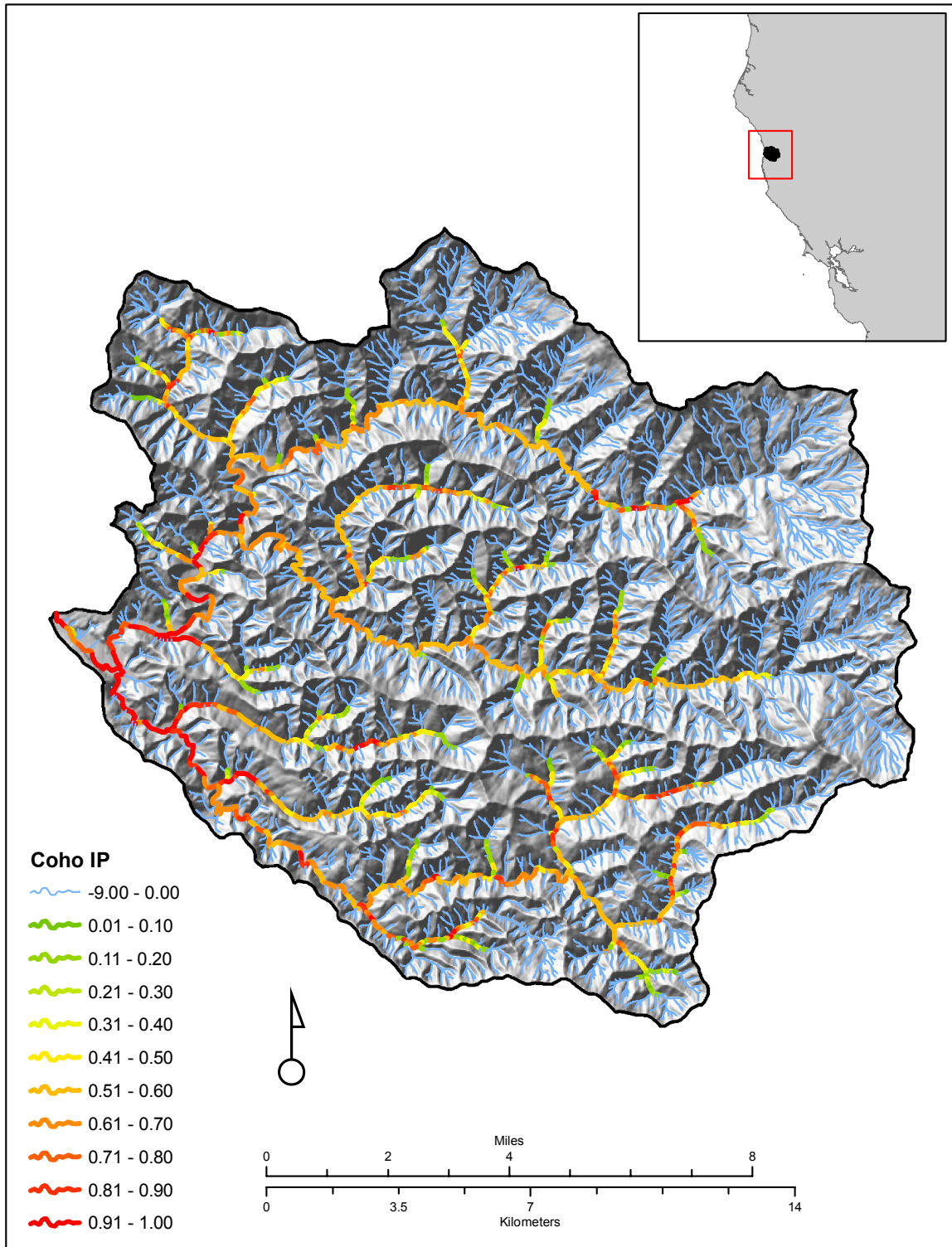


Plate 1: Intrinsic potential for coho salmon rearing habitat for the Ten Mile River.

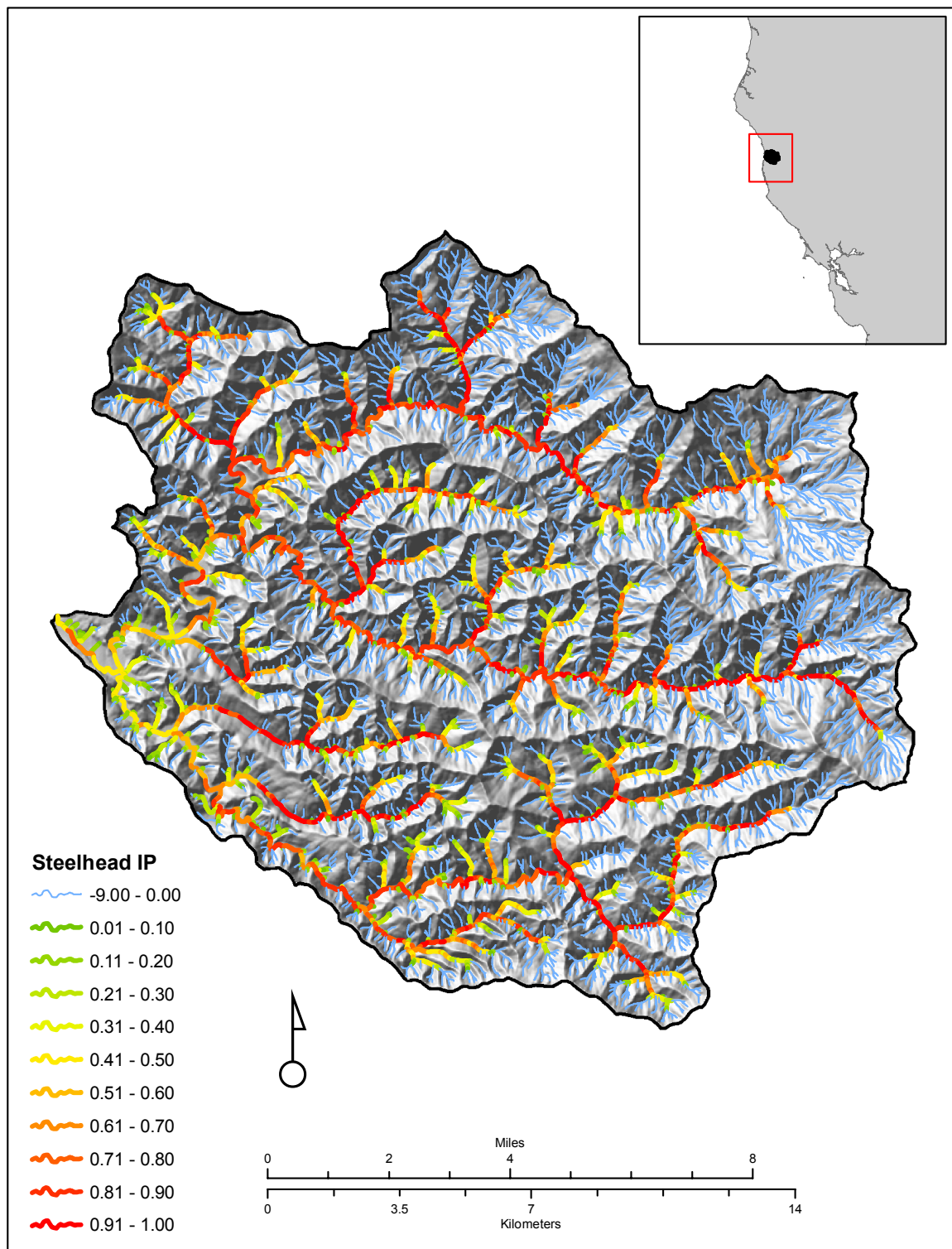


Plate 2: Intrinsic potential for winter steelhead rearing habitat for the Ten Mile River.

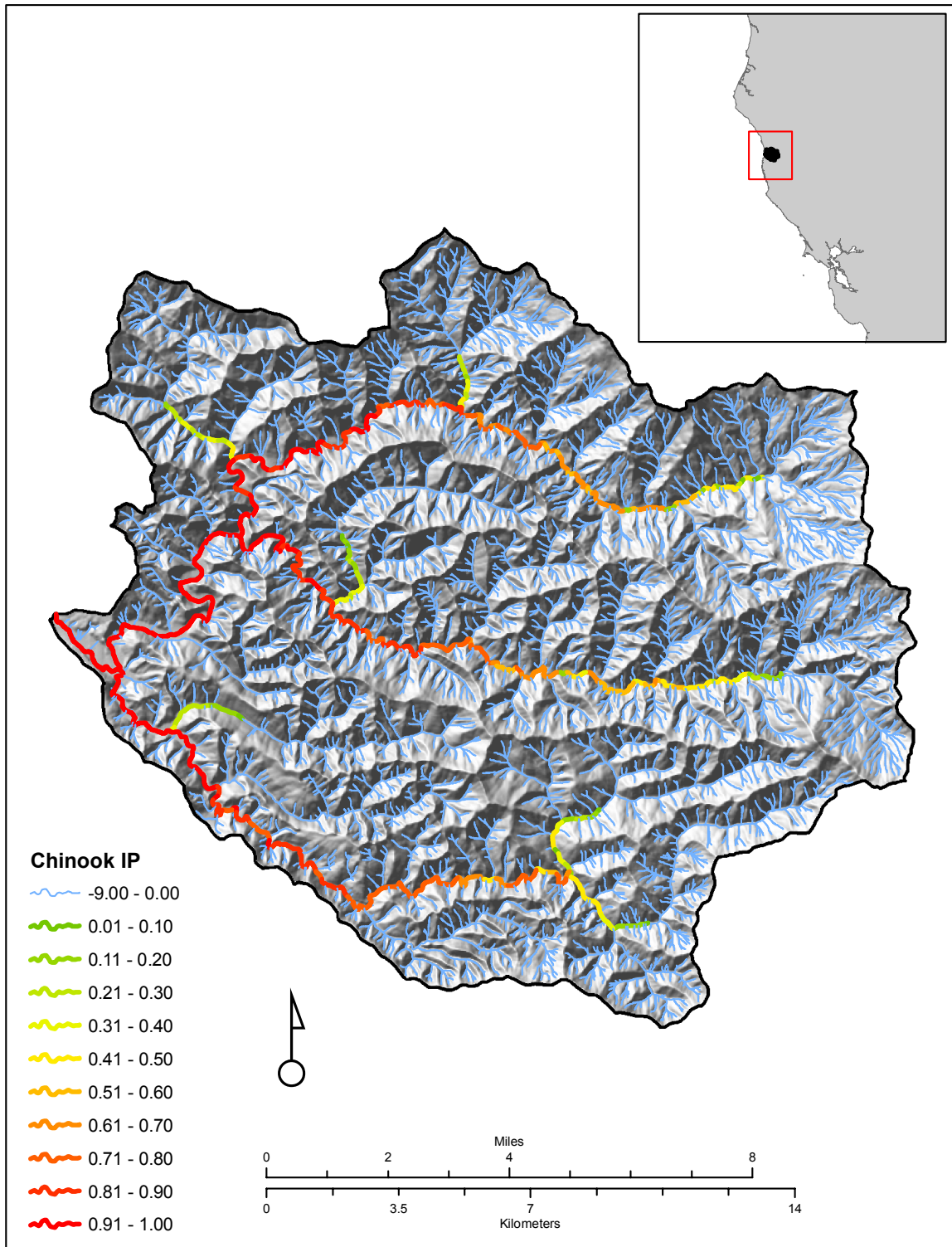


Plate 3: Intrinsic potential for fall-run Chinook salmon spawning and rearing habitat for the Ten Mile River.

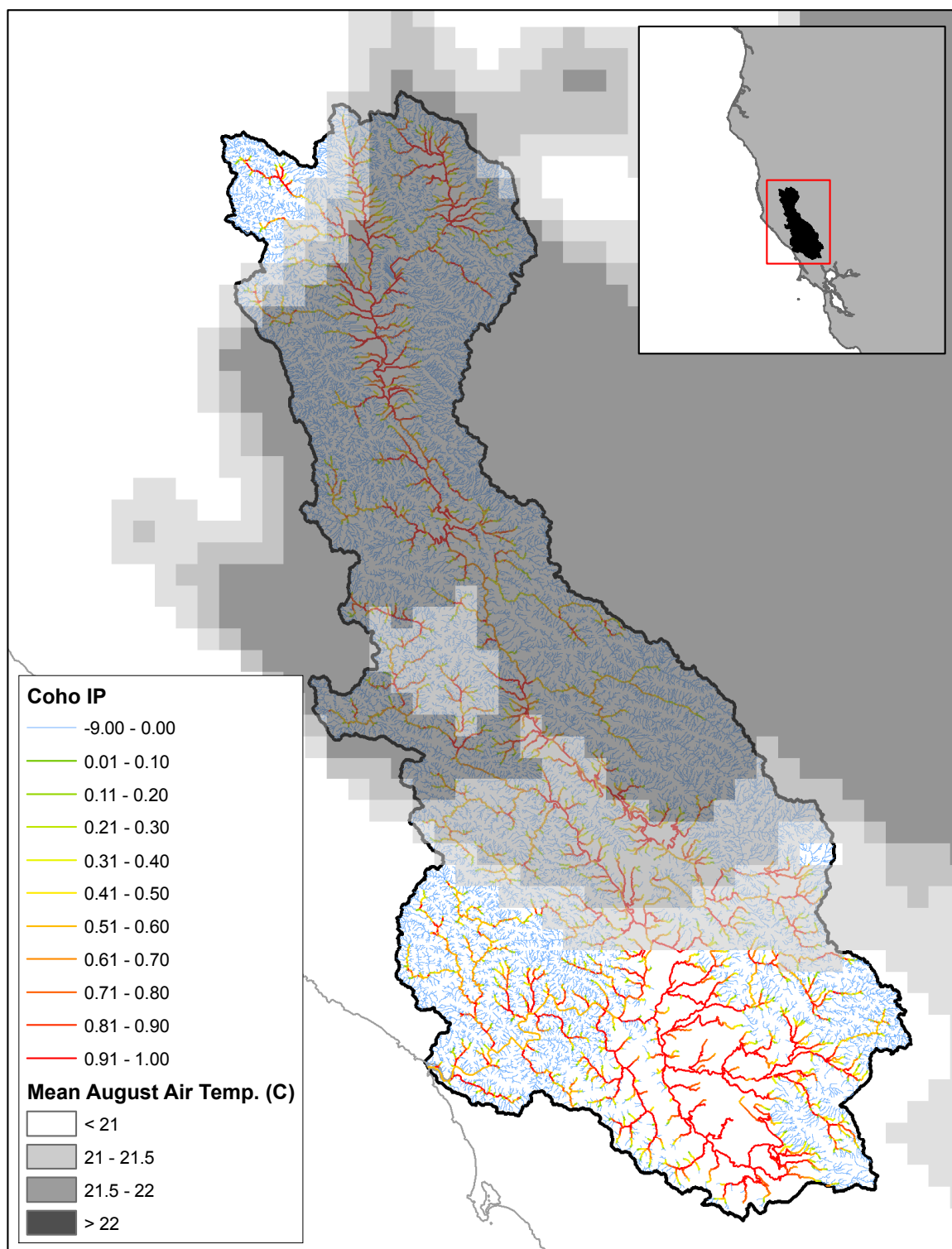


Plate 4: Intrinsic potential for coho salmon rearing habitat in the Russian River with areas from which coho salmon are likely to be excluded by high summer temperatures.